The Fine Structure of an Elementary Contractile System. By J. Roberto Sotelo and O. Trujillo-Cenóz. (*From the Instituto de Investigación de Ciencias Biológicas, Departamento de Ultraestructura Celular, Montevideo, Uruguay.*)*

Vorticella are ciliated protozoa that live in water, sometimes free, and sometimes attached by a long contractile peduncle (or stalk) to floating plant material.

Early light microscope studies of the animal revealed the existence of longitudinal and circular myoid fibrils linked with the contractile axis of the stalk. Observers reported (1, 15) that this system has the dual capacity of closing the oral extremity (cytosome), and of provoking the animal's characteristic shape change, from campaniform to spheroidal (while the peduncle itself contracts into a helical form.

In this Brief Note, it is not our intention to describe the morphology of *Vorticella*, but only to describe the fine structure of the myoid fibrils. It is sufficient to note that most of the myofilament bundles run near the cell periphery, some in close contact with the cell membrane, some inside the cell cytoplasm. At the (proximal) origin of the stalk, these longitudinal fascicles join to form a thick bundle (Figs. 1 and 3).

In the electron microscope, each observably discrete fibril in the system is made up of many elemental components, each 30 to 40 A in width, and of indefinite length (Fig. 2). Differences between contracted and elongated myofibrils are not clearly detectable, and we presume that a certain degree of contraction may always occur as a consequence of fixation (Fig. 4).

Electron micrographic profiles show that the fibrillar bundles exist in a close relationship with a membrane-limited canalicular system that resides both inside the bundles and paralleling and bounding them. Both the inner and outer canaliculi are integrated in the same system by connecting tubular bridges, but a striking difference distinguishes the two (Figs. 1 and 2).

The outer surface of the membrane limiting the inner canaliculi is in intimate contact on all sides and solely with the myofibrils; the outer canaliculi, on the other hand, are in contact with the myoneme on one side only, and while the contacting face is smooth and flattened, the remainder of the membrane surface is rounded and associated with particulate material of the cytoplasmic matrix.

A wealth of canaliculi intermingle with the myofilaments of the axial bundle of the stalk, and most of these appear to be connected with the canalicular network in the myonemes of the protozoan body. Cross-sections of the stalk show the spongy aspect of the myoneme (Fig. 4).

A canalicular system, comparable to that lined up along the bundles and connected with it, also exists in the cytoplasm (smooth and granular canaliculi). Myoid fibrillar components of *Vorticella* are similar in many respects to the myofilaments of smooth muscle cells (2), although the latter do not seem to be so closely associated with canilicular components (3).

Many investigators, including Porter and Palade (4–6), have demonstrated the existence within the cell cytoplasm of a canalicular system—the endoplasmic reticulum of Porter and coworkers (7)—that assumes difierent morphologic character and different relationships with other cellular components in various types of cells. Watson showed (8) that the nuclear envelope is connected to the system, or forms part of the reticulum. The Nissl bodies of nerve cells are agglomerations of ele-

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ments demonstrably continuous with the ER (9); the peripheral layer of the so called vitellin Balbiani body of spider oocytes is an ordered arrangement of endoplasmic reticulum cisternae (10); the recently demonstrated sarcoplasmic reticulum in vertebrate striated muscle (11, 12, 13, 14) is another specialized form of the reticulum.

In striated muscle fiber, the endoplasmic reticulum is in such close relation with the myofibrils that Porter and Palade ascribe (12) two functions to the system: (*a*) to channel metabolites to all parts of the cell and (*b*) in its aspect as continuous limiting membrane, to serve as an intracellular conductor of the excitatory impulse. The idea of a functional interaction between myofibrils and endoplasmic reticulum is undoubtedly attractive, especially in view of its presence in the elementary contractile system of protozoa. The canalicular system of *Vorticella* may indeed play a similar role in contraction and extension. Helical retraction of the stalk and changes in body shape take place all of a sudden, as if provoked by release of a trigger-like mechanism.

With regard to the stimuli that release the trigger mechanism (which involves excitation of the myoid structures and conduction of the excitation), these may originate in any part of the myoid system, particularly in those parts in contact with the cell membrane. It is tempting to explain conduction as a depolarization wave transmitted through the membrane-limited canalicular system associated with the myofilaments . . . but the concept is arbitrary since the myofilaments themselves may be capable of transmitting the contraction wave.

References

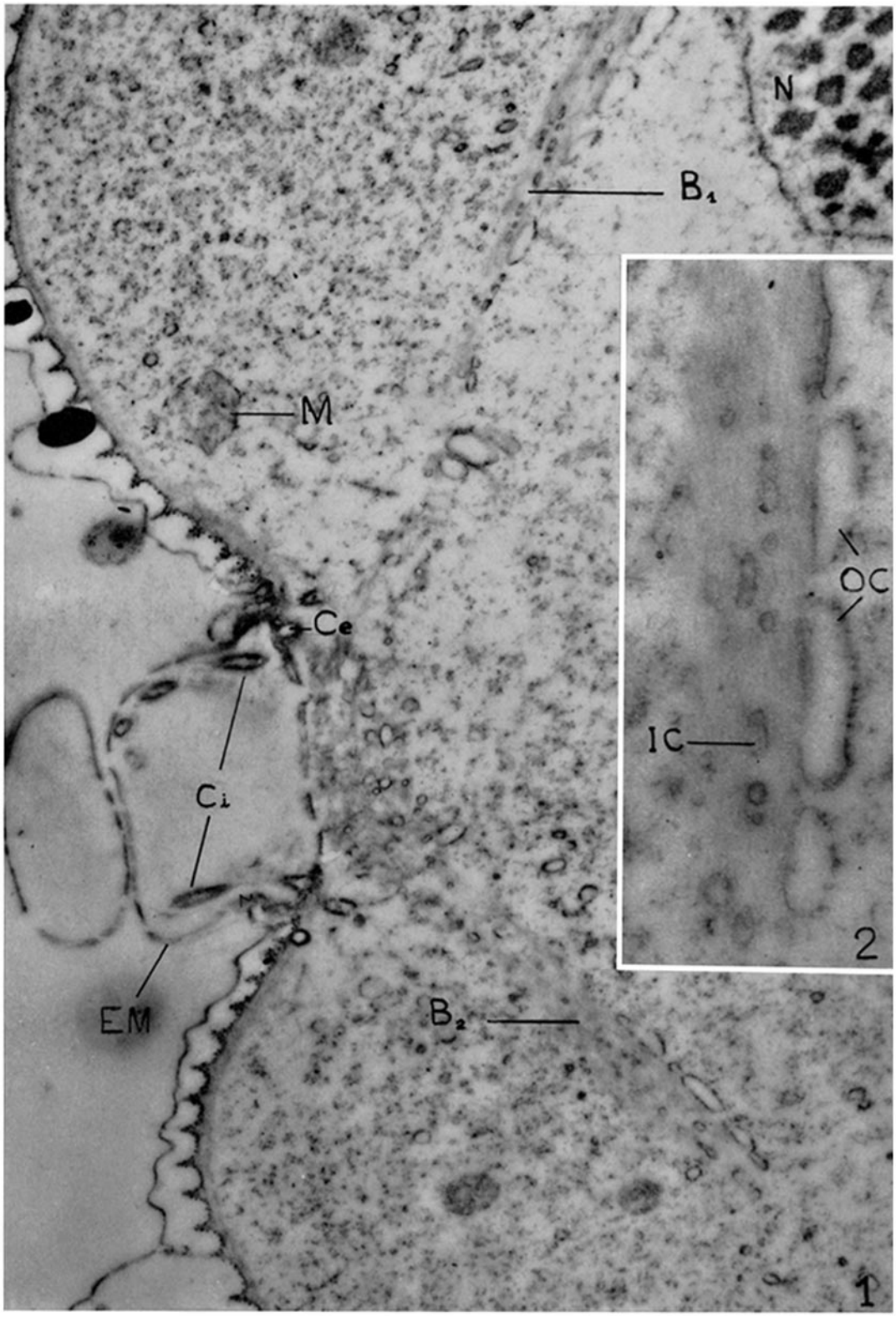
1. Delage, Y., and Hérouard, E., Traité de Zoologie concrete, tome 1. La cellule et les protozoaires, Paris, Schleicher, Frères, 1896.
2. Gansler, H. Electron Microscopy, Proceedings of the Stockholm Conference, Stockholm, Almqvist and Wiksell, 1956, 210.
3. Caesar, R., Edwards, G., and Ruska, H., *J. Biophysic. and Biochem. Cytol.*, 1957, **3,** 867.
4. Palade, G. E., and Porter, K. R., *J. Exp. Med.*, 1954, **100,** 641.
5. Palade, G. E., *J. Biophysic. and Biochem. Cytol.*, 1956, **2,** 547.
6. Porter, K. R., *J. Exp. Med.*, 1953, **97,** 727.
7. Porter, K. R., Claude, A., and Fullam, E. F., *J. Exp. Med.*, 1945, **81,** 233.
8. Watson, M., *J. Biophysic. and Biochem. Cytol.*, 1955, **7,** 257.
9. Palay, S. L., Palade, G. E., *J. Biophysic. and Biochem. Cytol.*, 1955, **1,** 69.
10. Sotelo, J. R., Trujillo-Cenóz, O., *J. Biophysic. and Biochem. Cytol.*, 1957, **3,** 301.
11. Bennett, H. S., Porter, K. R., *Am. J. Anat.* 1953, **93,** 61.
12. Porter, K. R., Palade, G. E., *J. Biophysic and Biochem. Cytol.*, 1957, **3,** 269.
13. Bennett, H. S., *J. Biophysic. and Biochem. Cytol.*, 1956, **2,** No. 4, suppl., 171.
14. Edwards, G. A., Ruska, H., de Souza Santos, P., and Vallejo-Freire, A., *J. Biophysic. and Biochem. Cytol.*, 1956, **2,** No. 4, suppl., 143.
15. Faure-Remiet, E., Rouiller, C., and Gauchery, M., *Arch. Anat. micr. et Morphol. exp.*, 1956, **45,** 139.

Explanation of Plates

Plate 80

Fig. 1. Low magnification electron micrograph showing the base of the cell body of *Vorticella campanulata*. The section is longitudinal but not medial in respect to the cell body. The photograph has been placed so that the oral extremity of the body is at the right and the base or origin of the stalk at the left. Only the periphery of the stalk, enveloping membrane, and part of the ciliary basal crown are visible. The most important elements that can be observed in the micrograph are two bundles of filaments, B_1, B_2, running from the right angles of the picture to its middle. Both bundles assemble at the base of the cell body where they contribute to form its myoneme. The canalicular system described in the text is clearly visible outside and inside the bundles. Note that at the origin of the stalk the inner canaliculi look similar to the outer ones. This detail is illustrated to better advantage in Fig. 3. *N*, nucleus; *M*, mitochondria; *EM*, outer pellicle surrounding the cell body and the stalk. *Ci*, and *Ce*, sections through cilia of ciliary basal crown. × 19,000.

Fig. 2. High magnification electron micrograph of a bundle of filaments similar to those visible in Fig. 1, B_1, B_2. Observe that the face of the outer canaliculi *OC* attached to the bundle is flattened and smooth where they make contact with the bundle, while their cytoplasmic face is bound with particulate material. The myofilaments (entirely) surround the inner canaliculi, *IC*. × 78,000.

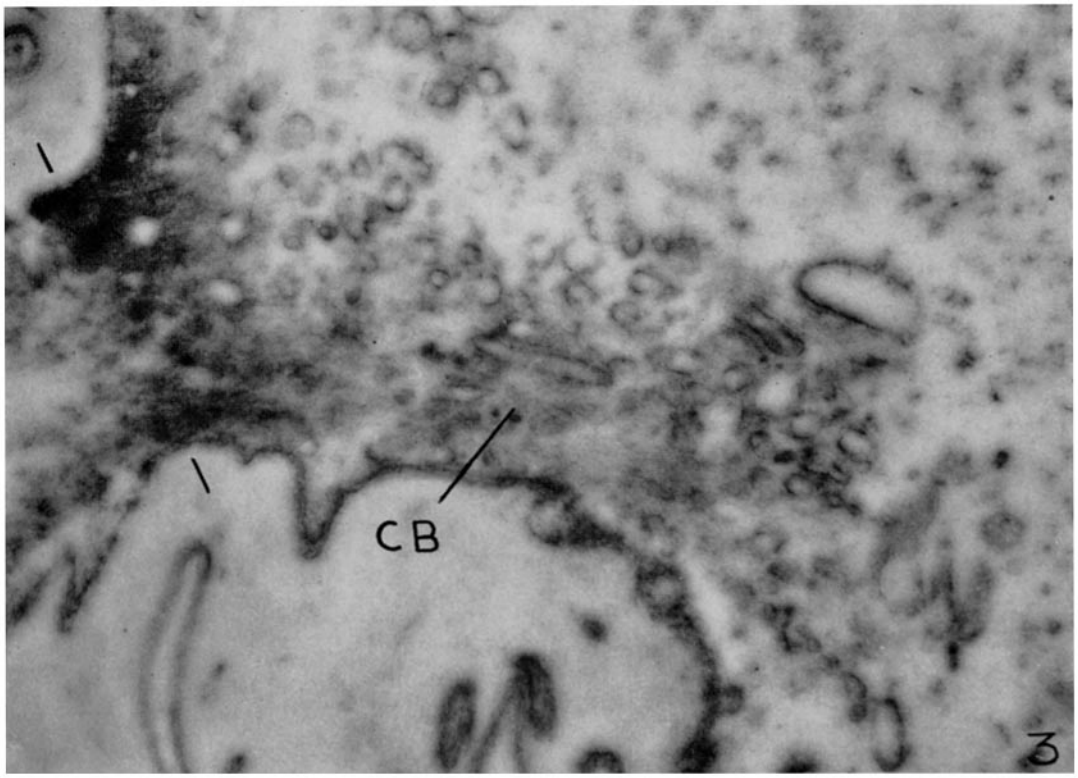


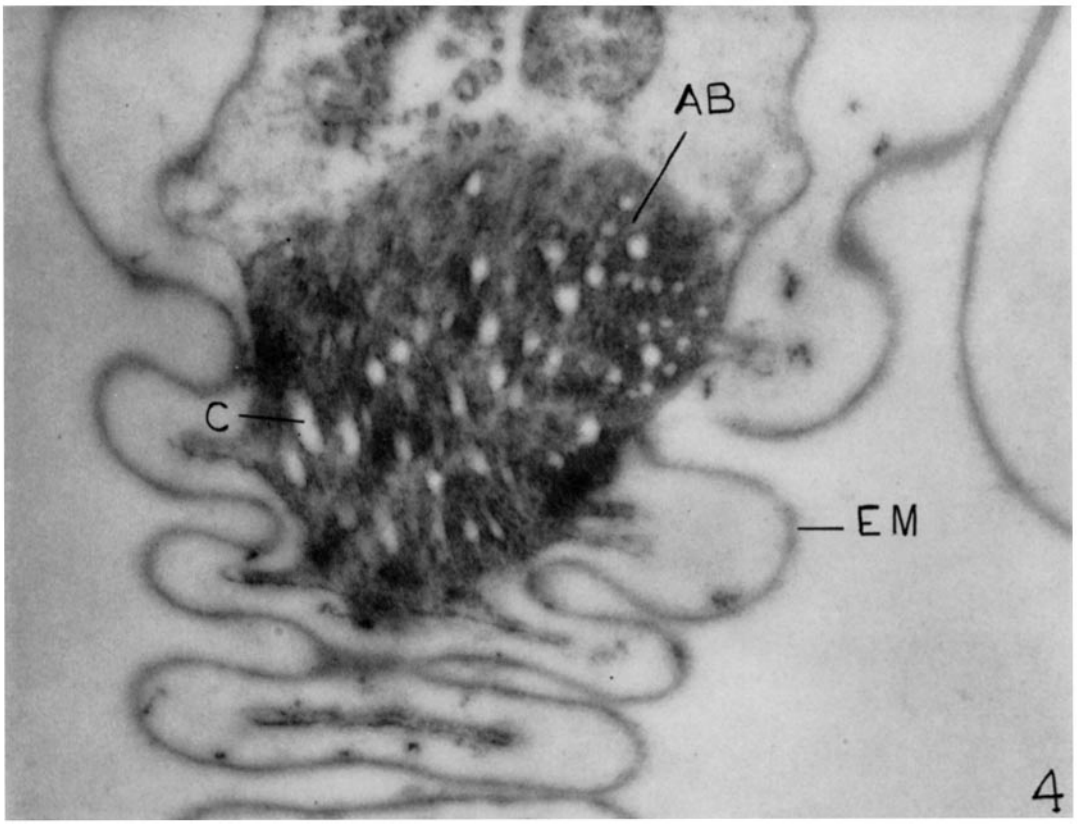
(Sotelo and Trujillo-Cenóz: contractile system)

PLATE 81

FIG. 3. Electron micrograph of the origin of the stalk of *Vorticella campanulata*. The narrow passage between the protozoan body and the stalk itself (indicated by lines) is seen filled by a dense bundle of myofilaments. Part of the cytoplasmic bundle is seen at *CB* where numerous profiles of canaliculi are intermixed with the filaments. Observe the similar features of all canaliculi (inner and outer canaliculi) in this region. The cytoplasmic membrane appears to be continuous with the membrane limiting the axial bundle. × 37,000.

FIG. 4. Electron micrograph showing a transverse section of the stalk of *Vorticella campanulata*. The axial bundle *AB* is composed of myofilaments and numerous canaliculi *C* most of which, at this level, are longitudinally oriented with respect to the stalk. The enveloping membrane *EM* shows many folds, indicating that the stalk was fixed in a contracted form. × 37,000.





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